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A seagrass shading experiment to determine the effects of a dredge plume

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Abstract
The environmental effect on seagrass of sediment plumes from dredging is often questioned in Environmental Impact Statements. Seagrass in southern Port Phillip Bay, Victoria, Australia, was shaded in winter and spring to the same level as the worst scenario of shading by an expected dredge plume. After 90 days of shading, *Heterozostera nigricaulis* shoot numbers reduced by 61%. After 134 days of shading, the shoot density reduced by 84%. Some of the shades were removed after 71 days of shading, but shoot density continued to decline for a further 40 days in these plots, and no recovery was observed throughout this time. In these plots, where shades had been removed, shoot densities then stabilised and no further loss was reported at day 134. A minimum light requirement of 12.5%–25.6% appears to be suitable for sustaining *H. nigricaulis* beds. (*The Victorian Naturalist* **129** (3), 2012, 97–108)

Keywords: *Heterozostera nigricaulis*, shading, dredging, shoot density, light requirement

Introduction
One of the major impacts of dredging is an increase in turbidity and suspended sediments in the water column and the subsequent decrease in light availability to benthic plants. This research describes site and seagrass specific shading experiments to determine the potential effect of a dredge plume.

Much research has been carried out on the susceptibility of seagrasses to shading (Bulthuis and Woelkerling 1983; Goldsborough and Kemp 1988; Peralta *et al.* 2002; Gacia *et al.* 2005). Little of this research has been applied to understanding the effects of reduced light conditions on seagrass under a dredge plume. In an excellent review of the environmental impacts of dredging on seagrasses, Erftemeijer and Lewis (2006) looked at 45 case studies globally, accounting for the loss of about 21 000 ha of seagrass. They recommend site specific evaluations of the effects of dredging plumes. Recently, Mackey *et al.* (2007) studied many parameters of *Amphibolis griffithii* biology under shade conditions, in areas adjacent to harbour dredging programs in their region. Although a wide range of morphological and physiological variables responded to reduced light availability, the majority of variables showed substantial recovery after 42 days. This was one of the first experiments in the peer reviewed literature to match site specific dredging activities with response by seagrass to those activities. Previous work usually appeared in environmental effects and impact statements and internal government or corporate reports. Previously accepted methods used in research on seagrass, with the modelled reduction in light caused by a dredging plume are brought together and the way that site-specific evaluations can be made is shown.

Unlike Mackey *et al.* (2007), this study tested only changes in shoot density of seagrass, because this is the most likely and most reliably consistent parameter to be affected by shading. Funding was not available for measuring many morphological and physiological variables. This study demonstrated a method of determining shading effects on seagrass in the most efficient way. Recently, Bité *et al.* (2007) measured the photosynthetic efficiency of *Zostera capricorni* and *Halophila ovalis* using Pulse Amplitude Modulated fluorometry in short-term shading. They found that photosynthetic efficiencies and effective yields increased significantly in both species for shaded plants. Both species showed a strong degree of photo-adaptation to shading that may allow them to tolerate and adapt to short-term shading.

The seagrass species examined during the present study was *Heterozostera nigricaulis* J. Kuo, family Zosteraceae, a narrow-leafed plant that inhabits subtidal, sheltered and moderately exposed sandy bottom environments in Port Phillip Bay (Bulthuis 1983). Prior to 2005, *Heterozostera nigricaulis* was named *Heterozostera tasmanica* but Kuo (2005) distinguished between these species, and identified the *Heterozostera* growing in Port Phillip Bay as *nigricaulis.*

The variability of seagrass morphological measurements is large and often prevents statistically-sound statements being made about measurable changes in less than five years. Productivity measurements, i.e. of growth using hole punching (Short and Duarte 2001), were initially identified as an appropriate tool for determining seagrass health during this shading study. However, during the initial stages of fieldwork, it was evident that these measurements could not be undertaken in an accurate or time efficient manner. Shoot density has been demonstrated to be a useful tool to assess seagrass population status and it has been extensively used over the last decade (for a review see Marba *et al.* 2005).

This study documents an experiment that aided in determining how *Heterozostera nigricaulis* responds to the low levels of light expected to be caused by dredging in southern Port Phillip Bay, Victoria, Australia. The objective of the experiment was to determine the impact of reduced light on *H. nigricaulis* by shading for specific time periods. The degree of shading was equivalent to the expected reduction in light from a dredging plume. The recovery of *H. nigricaulis* upon return to natural light intensities was also examined for a short period. The compensation depth of this species was used to estimate the minimum amount of light the species requires for survival.

This study was undertaken during the winter and spring months, and provides information on seagrass response to reduced light intensities only during those seasons. Some discussion has been provided in the text regarding previous seagrass shading studies undertaken in summer.

Methods

Site Selection

Sites were selected in consultation with the dredging proponent, prior to undertaking the shading study, which considered the following:

- Plume modelling data to determine the key sites where the dredge plumes will reduce light available for the seagrass *H. nigricaulis*;
- Sites where data have been previously collected. There was a considerable amount of useful data available from previous studies in Western Port Bay (Bulthius 1983; Bulthius and Woerlkerling 1983);
- Whether the seagrass meadows were permanent or ephemeral, as the monitored communities needed to be present for the duration of the environmental monitoring program. This was determined from previous knowledge;
- Shading experiments were not undertaken within marine protected areas;
- Sites were checked for accessibility and logistical constraints, because of the need to work in readily accessible areas and in low wave energy environments suitable for conducting shading experiments, and
- Information on the physical characteristics of each potential study site was sought from initial site inspections.

A single location was selected for the shading experiment, approximately 2 km east north-east of Sorrento (Fig. 1). There are numerous places in Port Phillip Bay where *H. nigricaulis* grows (Blake and Ball 2001); however, most of these are either sparsely vegetated, or grow within marine protected areas. The location selected needed to

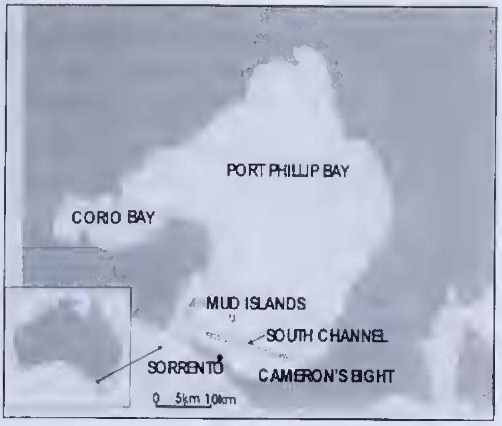

Fig. 1. Port Phillip Bay. The shading experiment was at Sorrento and proposed dredging in South Channel and at Queenscliff.

be at the representative depth of 4–5 m and only a few places exist which contain continuous beds at this depth. This nominal depth was chosen considering that *H. nigricaulis* commonly occurs in southern Port Phillip Bay between 2 m and 6 m depth (Blake and Ball 2001).

Light measurements and justification

To predict the amount of incident light likely to occur under the dredge plumes and establish the light intensities for future shading experiments the following data were reviewed:

- The initial model was based on turbidity modelling data obtained from continuous dredging in the South Channel for three months (March–May 2005) (Cardno, Lawson and Treloar 2006). The turbidity modelling was used to establish the likely total suspended solid (TSS) concentrations over relevant areas of seagrass, from which the expected light attenuation and benthic light levels were then estimated using the following relationship: TSS vs light attenuation coefficient derived from a laboratory based experiment undertaken by Longmore *et al.* (2004).
- Incidental TSS measurements taken inside the dredge plumes during the trial dredging program; and
- The PAR (photosynthetic active radiation) data from the fixed benthic light meter sites during the trial, i.e. Mud Island, Cameron's Bight etc.

Light intensity was measured at Sites 4 and 6 of the six replicate sites (Fig. 2), to record incident light intensities at the sea-bed under the shades and without shade. Light attenuation coefficients were calculated for the location by comparing sea-bed and mid-water readings. Light was measured using 2π Odyssey® Photosynthetic Irradiance Loggers (with built in sensors), programmed to take light readings at 10 minute intervals. These loggers measure down welling-light and will not detect light coming in from the side of the shades.

The light loggers measured light in PAR expressed in μmole/m^2/s and were calibrated against the Primary Industries Research Victoria (PIRVic) Licor® meters. The sensors on the loggers were cleaned every 10–14 days at the same time as the light data were downloaded.

The loggers were secured by star pickets to the sediment, with the sensor protruding just above the top of the picket, and run continuously for two weeks, at which time the data were downloaded and the logger redeployed. One logger was placed under the shade in the mid-

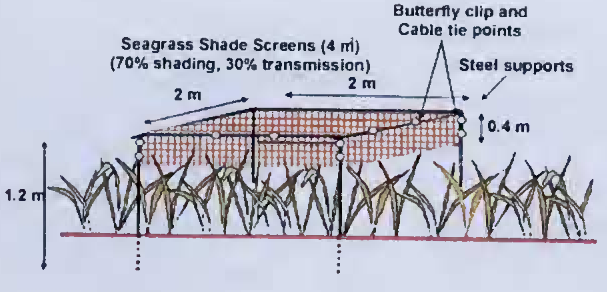

Fig. 2. Shade screens over seagrass.

dle of the plot, one mid-water 1.3 m above the seabed and one on the seabed (0.3 m above the bottom).

The data from the turbidity modelling and trial dredge program were used to predict the average light reduction likely to occur in the vicinity of seagrass beds. The equation used for estimating light attenuation was based on the Bougert-Beer Law:

$AC = \ln (I_{Z1}/I_{Z2})/Z$ **Equation 1**

where AC is the light attenuation coefficient (m^{-1}), I_{Z1} is the light at depth 1 (seabed), I_{Z2} is the light at depth 2 (mid-water) and Z is the difference between depths 1 and 2.

The modelled TSS concentrations at selected seagrass sites, during 11 weeks of dredging in South Channel East, rarely exceeded 5 mg/L (Cardno, Lawson and Treloar 2006). Since this concentration is expected for less than approximately 10% of the time, a more realistic concentration likely to be regularly encountered during dredging is 3 mg/L. This concentration of material suspended by dredging would be in addition to ambient (background) TSS concentrations of approximately 2 mg/L (Longmore *et al.* 2004).

The relationship between TSS and light attenuation (Longmore *et al*, 2004), was then compared to approximate benthic light levels likely during dredging. This laboratory-based study derived relationships for one sediment sample from the South Channel that found that, for a given plume TSS concentration, the resultant amount of light attenuation due to the plume alone, i.e. excluding background, was:

$AC=0.115 \times TSS$ ($r^2=0.89$) **Equation 2**

where AC is the light attenuation coefficient due to the plume from South Channel (m^{-1}) and TSS is the total suspended solid concentration in the plume (mg/L); r^2 is the coefficient of determination. Therefore, for a plume TSS of 3 mg/L, the plume related light attenuation coefficient would be 0.345 m^{-1} If background light attenuation is around 0.2 m^{-1} in the south of the Bay (Longmore *et al.*, 1996), then, using Equation 1, the resultant light intensity at a nominal depth of 4 m is approximately 10% of surface irradiance. The incident light intensity proposed for experimentation purposes, i.e. light intensity under the shades at 4 m, was at 6% of surface irradiance. The minimum light limit reported for *H. nigricaulis* was 5% of sub-surface light (Bulthuis 1983).

Under natural conditions, with a background light attenuation coefficient of 0.2 m^{-1}, the incident light intensity on the seabed at 4–5 m depth is between 33% and 41% of surface irradiance. Therefore, a shade cloth with 70% shading intensity was chosen for use in the shading study, as this resulted in a theoretical incident light intensity of between 9% and 12% surface irradiance under the shades. This was similar to the average level of light reduction expected under the dredge plumes in the vicinity of the seagrass meadows.

Irradiance on the seabed (I_{Z1}) was used along with the irradiance mid water (I_{Z2}) to calculate the light attenuation coefficient (AC) using the Bougert-Beer Law (Equation 1). The irradiance just below the surface (I_0) was then calculated (Equation 3). The surface irradiance was calculated for average light measurements between 1200 h and 1300 h for the duration of the study.

$I_0=I_{Z1} \times e^{AC \times d}$ **Equation 3**

The percentage surface irradiance on the seabed was calculated using Equation 4; the percentage of surface irradiance under the shades was calculated using Equation 5 and the percentage of light under the shade as compared to the seabed was determined using Equation 6.

% Surface irradiance on seabed = $I_{z1}/I_0 \times 100$ **Equation 4**

% Surface irradiance under shade = $I_{shade}/I_0 \times 100$ **Equation 5**

% Light under shade compared to seabed = $I_{shade}/I_{z1} \times 100$ **Equation 6**

Experimental Design

The methods of Bulthuis (1984), Kirkman (1989), and Longstaff and Dennison (1999) were adopted for designing the work. Shade screens were put in a dense and continuous seagrass meadow at an average depth of 4 m. Shoot density at this site was between 300–800 shoots m^{-2}. Shades were steel frames each of 2 m x 2 m and 60 cm high, on which were connected shade cloth screens (Bulthuis 1984), using plastic shade cloth clips and cable ties. The frame was held in place by star pickets. The sides of the shades were approximately 200 mm above the sea-bed (Fig. 3). Non-shaded control treatments using steel frames (of the same dimensions) were also established at each of the sites (Fig. 2). Our shades were smaller than those of Mackey *et al.* (2007), but had skirts around them to reduce lateral intrusion of light.

Although Longstaff and Dennison (1999) recorded minimal exchange of rhizomes between transplanted and non-transplanted seagrass from biomass sampling under shades, the rhizome mat was cut to an approximate depth of 10 cm around the boundary of each shade and the controls to prevent translocation of material between non-shaded seagrass bed and shaded sites. The effects of rhizome cutting could have been investigated by also including controls with rhizomes that were not cut. However, these controls were not established because of logistical constraints associated with the need to effectively sample all of the sites in a single day and because of the findings of Fitzpatrick and Kirkman (1995) and Longstaff and Dennison (1999).

Treatments

As depicted in Fig. 2, there was a treatment where the seagrass was shaded for the entire duration of the experiment (shaded treatment); and a treatment where seagrass was shaded until seagrass health had visually diminished, at which point, the shades were removed (recovery treatment).

Eighteen replicates were used for each treatment for the shoot density counts, to reduce the level of variation within each treatment. Experience with random or haphazardly thrown quadrats showed that 18, 0.0625 m^2 quadrats, in *H. nigricaulis* was a reasonable number and size to reduce the coefficient of variation to a minimum. To further reduce variation, fixed quadrats were used (Austin, 1981). Due to time constraints, a power analysis was not undertaken to determine the appropriate level of replication and quadrat size.

The shading experiment consisted of a total of six replicate sites at one location (see Fig. 2). Shade screens for each experimental treatment (shaded and recovery), plus a control treatment, were deployed at each of the six sites.

Placing clear plastic shades at the control sites, in accordance with the methods described in Kirkman (1989) was considered. Previously, clear plastic shades have been used during shading studies to mimic the shade cloth, by

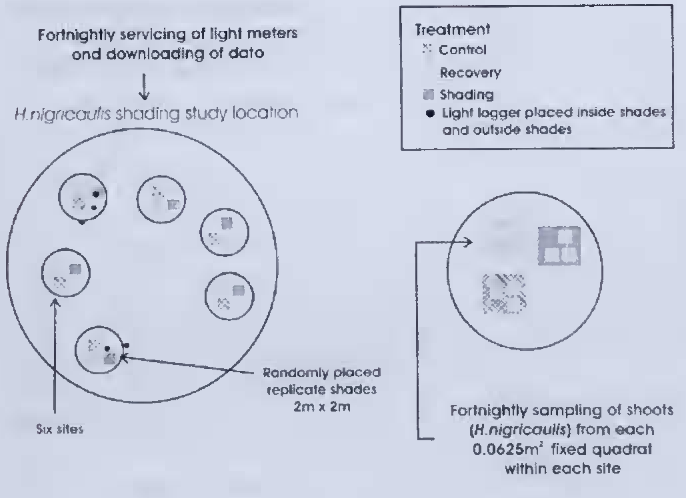

Fig. 3. Experimental design for the *Heterozostera nigricaulis* shading experiment.

reducing the amount of water flow over the seagrass present under the shades. Clear plastic shades were not deployed, however, as they would have had significant fouling, making them unsuitable as controls and failure to account for shade cloth effects, other than light reduction, was considered to be less significant than the confounding effects of using plastic shade cloth. Kirkman (1989) also reported that there was no difference in productivity of *Ecklonia radiata* (a kelp) under clear plastic controls, compared to the unshaded controls, which suggests that there is no impact from the shades themselves, in relation to limiting water flow and reducing the settlement of suspended particulates on benthic plants. Mackey *et al.* (2007) also faced this problem, but eventually did not use procedural controls.

Counts and visual observations

Shoot density is the least variable of all seagrass response variables and is a key parameter included in any monitoring program (Duarte and Kirkman 2001). It is also one of the most reliable parameters (Collier *et al.* 2007). No biomass sampling via coring was undertaken because of its destructive nature and was also not considered suitable because fixed quadrats were used to monitor changes in shoot density (a much more reliable parameter). Fixed quadrats in terrestrial plants have been used successfully to reduce variability (Austin 1981) and their use is argued by Hartnoll (1998) in marine ecosystems. Marba *et al.* (2005) used shoot density in fixed quadrats as a means of measuring seagrass population dynamics very successfully in the Mediterranean. Fixed quadrats remove the problem of environmental heterogeneity and permit the detection of relatively small changes. There are problems with the representativeness of the quadrats and changes within them may be artefacts of biological processes rather than community changes. There are also constraints on the statistical analysis of time series based on fixed quadrats.

More subtle responses such as changes to seagrass physiology were considered, including the measurement of *in situ* photosynthesis via Pulse Amplitude Modulated (PAM) Fluoremetry. This technique, however, previously has not been applied to monitoring for seagrass meadow-wide health, or for detecting changes during dredging and, so, was discounted (Dr Peter Ralph, University of Technology, North Sydney pers. comm. 2006). The use of physiological or biochemical monitoring tools during a dredging program also has limitations, i.e. practicality of sampling and time to analyse results. The focus was to document the integrated response of the seagrass using an easily quantifiable and rapid assessment technique, i.e. shoot density.

Shoots were defined as black, lignified stems with green shoots attached or small, usually single, leaves that grew directly from underground rhizomes (Kuo 2005). When the term 'new shoots' is used it refers to these single green leaves which grew from the sandy substratum.

Heterozostera nigricaulis shoots were counted within the shaded, recovery (following shade removal) and control treatments using 25 cm x 25 cm fixed (0.0625 m^2) steel quadrats. Three quadrats were placed under each shade screen. The total number of shoots (primary and secondary shoots were considered a single shoot in the counts) present within the 0.0625 m^2 quadrat area was recorded, with the exception of dead shoots. Dead shoots were those that had no leaves or a few dead leaves. Qualitative observations were also made throughout the experimental period, which included documenting any morphological changes in seagrass health, such as changes in leaf width, changes in shoot, leaf and rhizome colour and presence/absence of epiphytes.

Timing and Frequency of Sampling

The experiment began during the week commencing 5 June 2006 and ran for four months, from June to October 2006. Shading experiments were undertaken on *H. nigricaulis* at approximately the same time of year as dredging is proposed, i.e. primarily winter and spring. Shoot density was reported at between 14 and 24 day intervals within the shaded and control treatments over the experimental period on days 0, 19, 35, 49, 61, 78, 95, 110 and 134 and in the recovery treatment on days 0, 35, 61, 78, 95, 110 and 134. Shades were removed from the 'recovery sites' on day 71.

Statistical design and analysis

For analysing the percentage change in shoot density, compared to Day 0, a value of 100 was added to the percentage change reported in each quadrat, to ensure that all of the values reported a positive number for the statistical analysis. Average shoot density for the three quadrats present under each shade screen was calculated for undertaking the statistical analysis.

For the purpose of the data analysis, the recovery treatment was excluded, to avoid an unbalanced dataset, i.e. eight sampling events in the shaded treatment and six sampling events in the recovery treatment and, therefore, the shaded treatment was directly compared with the control treatment. Compositing of the two datasets, i.e. shaded and recovery, also would have meant that the main effects and interactions on Days 18 and 52, where no data were collected for the recovery treatment, could not have been fully examined.

Results

Percentage change in shoot density

The percentage change in shoot density in the shaded treatments, compared to the control treatment over the four month experiment from June to October 2006, is illustrated in Fig. 4a. A gradual decline in the number of shoots was evident after approximately two months of shading. A significant decline of 61% in the number of shoots was detected in the shaded treatments after three months, at Day 95.

Percentage change in seagrass shoot density in the controls was near zero during winter then increased during spring from Day 78. Seagrass shoot density under the shade cloths continued to decline until the last sampling event (Day 134), where there was an 84% reduction in the number of shoots reported after almost four and a half months of shading, this was significantly different from the controls (p=0.002).

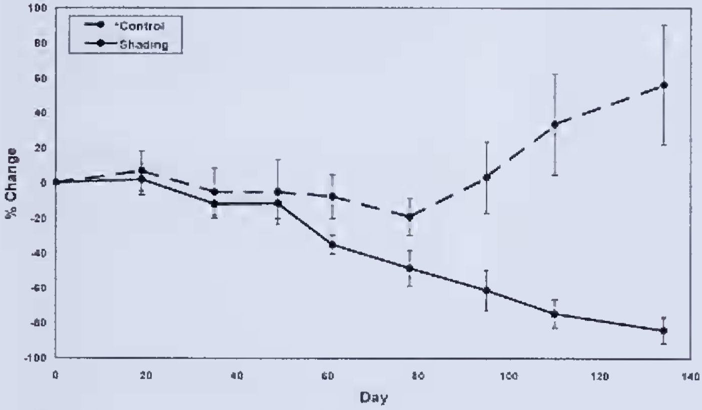

Fig. 4a. Percentage change in shoot density for control and shaded *Heterozostera nigricaulis*. Vertical lines are one standard error about the mean.

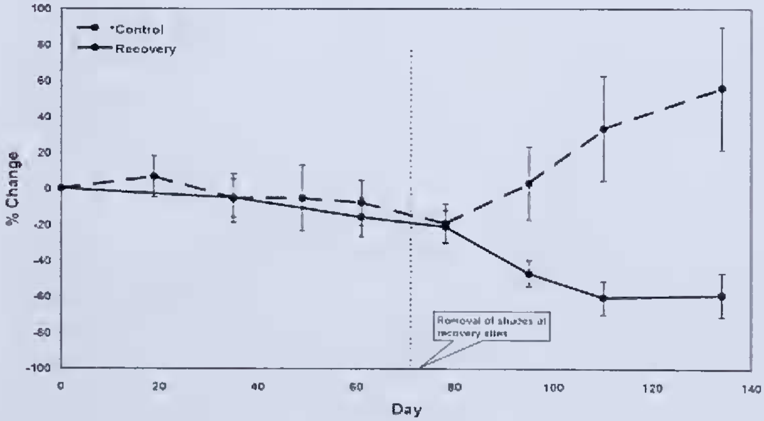

Fig. 4b. Percentage change in shoot density for control and recovery treatments for *Heterozostera nigricaulis*. Vertical lines are one standard error about the mean.

Shoot density did not significantly change in the recovery treatment, compared to the controls during the two month shading period (p>0.05). Shades were removed from the recovery sites, however, because a number of the sites were showing a considerable decline in seagrass health based on qualitative observations (see Observed Changes below). Following the removal of the shades in the recovery treatment (Fig. 4b), on Day 71 of the experiment, seagrass shoot densities continued to decline significantly until Day 110, compared to the controls. Shoot density had reduced to more than half (60 ± 7%) since the beginning of the experiment, whereas shoot density in the controls increased 54% (p=0.012). The significant reduction in shoot density in the recovery treatment, compared to controls was partly due to seagrass in the controls responding to a change of season, from winter to spring, whereby new shoots were produced. This significant difference, however, was also partly due to shoot densities in the recovery treatment reducing by a further 40% since the shades were removed, which suggested a lag effect in seagrass response to the removal of shading. The continued decline in shoot density up to Day 110 may have been due to the inability of plants to recover before that because of a lack of stored material (Fig. 4b). No recovery was observed, but two months after shade removal, at Day 134, shoot densities appeared to stabilise (59 ± 9%), where no further loss in shoot density was reported (Fig. 4b). This suggests that seagrass in the present study may take many months to fully recover from shading.

New shoots were first documented in the control treatment on Day 95, at the beginning of spring, whereas very little new shoot growth was reported in the recovery treatment. Fewer new shoots were reported within the shaded treatment than in the controls. There was also new shoot growth throughout the control treatment on Day 110, but only a few shoots were reported in the recovery treatment. Two months after shade removal, however, on Day 134, large numbers of new shoots at all six sites were reported in the recovery treatment resulting in no net loss of shoots, compared to Day 110 (Fig. 5).

The changes reported in shoot density were quite variable over time, both within sites and between sites (Fig. 5). This was particularly evident from the large standard error bars depicting variability between the quadrats, within sites. There was a high degree of variability in seagrass response observed between the sites. Note that, with random or haphazardly thrown quadrats, the variance would have been much greater. In one instance, within the shaded sites, the seagrass densities increased, i.e. Site 4 shaded treatment, whereas at all of the other shaded sites, seagrass densities decreased. Similarly, in some instances seagrass densities in the controls decreased, e.g. Site 5, whereas shoot density at other control sites increased, e.g. Site 2 and Site 3, after day 78 (see Fig. 5). Despite the level of natural variability, there was sufficient replication within the treatments (n = 6) to observe significant differences in shoot densities between the shaded sites and the controls.

Observed changes

Leaves in the shaded treatment became paler after one month of shading, but had relatively similar phenotypic characteristics compared to the controls. The main difference detected after shading was the reduced overall epiphyte cover.

After two months of shading, no obvious morphological changes were apparent in shaded seagrass, except that the leaves were now clean of epiphytes. The shoots and leaves still appeared to contain chlorophyll pigment.

After almost three months of shading, by Day 83, dead, blackish-brown seagrass leaves were apparent. Average leaf width was also measurably lower in the shaded treatment compared to the control treatment from Day 61 until the end of the experiment (Table 1).

Adventitious roots (Cambridge *et al.* 1983) were reported in the recovery treatment two months after shade removal. Some flowering also was reported in the recovery treatment at this time; however, there was considerably less flowering compared to controls.

Incident light intensity

Light intensities measured at Sites 4 and 6 in the *H. nigricaulis* experiment are presented in Table 2. Light attenuation coefficients (AC) were calculated at each site and the amount of light available to the plants under the shades was determined. The average light intensity measured from beneath the shades at Sites 4 and 6 was considerably lower than expected, with PAR concentrations reported between 5 and 15 μmol/m^2/s. The 70% shade cloth was intended to reduce light intensity to between 9% and 12% of sub-surface irradiance under the shades, at 4–5 m depth. As indicated in Table 2, however, light intensities beneath the shades were between 1% and 3% of sub-surface irradiance. The variability in light intensity under the shades between June and September may be attributed, in part, to seasonal and diurnal variations in the amounts of sub-surface light available.

The reduction in sub-surface irradiance compared to predicted levels was due to large amounts of silt and particulate material settling on the shades between cleaning events. Natural incident light intensity reported on the seabed

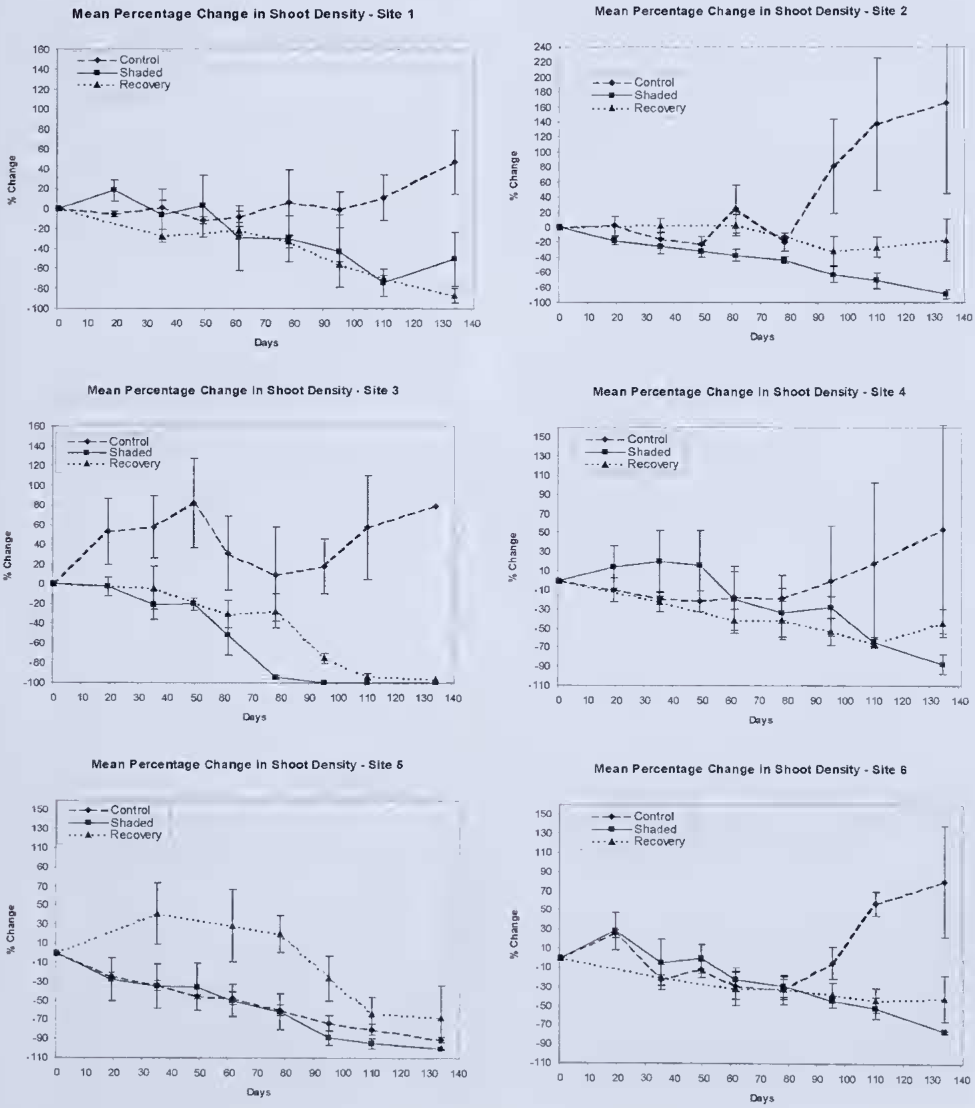

Fig. 5. Percentage change in shoot density at individual sites. Vertical bars are one standard error about the mean.

(I_{z1}), mid-water (I_{z2}) and sub-surface (I_0) all increased over the experiment, probably largely due to increasing light from winter to early spring. The amount of sub-surface irradiance reaching the seabed varied between 68% in June and 34% in September. The higher amount of sub-surface light reported on the seabed in June compared with July was due to low light attenuation and good water clarity during early winter. AC reported from June 2006 to September 2006 varied from 0.10 to 0.27 m^{-1}.

The AC values determined may have been affected somewhat by the small distance, i.e. 1 m, between the light loggers, which were placed mid-water and on the seabed. A longer path length, i.e. >1 m, would have been preferable, but the elevated logger could not be placed any higher than 1 m due to the shallow nature of the sites; any higher and the light probes would have presented a hazard to boating.

Discussion

Heterozostera nigricaulis shoot density under shading significantly decreased over time. After three months of shading, shoot numbers reduced by 61%. Shading of the same species in Western Port in winter caused a similar decline in shoot density after two and a half months (Bulthuis 1983). Bulthuis (1983) reported that seagrass took longer to reduce in density in winter, compared to the summer months. In contrast with a spring and summer shading study undertaken on *H. nigricaulis* in Corio Bay (Fig. 1), where a 100% loss of shoots was reported after three months of shading with 70% reduced incident light (Bulthuis 1984), the current experiment was carried out in winter and early spring. All shoots were not lost, although four and a half months of shading did reduce shoot density by 84%. The difference between the rapid loss of shoots in the Bulthius (1984) experiment and the slower reduction in density in this one is that his plants may have showed a greater tolerance to reduced light intensities at 4 m depth compared with 2 m, and the difference in season.

The changes in shoot density were variable over time, both within sites and between sites. There was also a high degree of variability in observed seagrass response to shading between

Table 1. Leaf width changes under shade and at control.

Date	Day No.	Treatment	Leaf width (mm)	SE	Number of leaves
5 Aug 2006	61	shade	1.6	± 0.2	52
	61	control	2.0	± 0.2	52
8 Sept 2006	95	shade	1.6	± 0.1	57
	95	control	2.1	± 0.3	53
17 Oct 2006	134	shade	1.6	± 0.2	43
	134	control	1.8	± 0.2	52

Table 2. Average light intensity taken at Sites 4 and 6, between 1200 h and 1300 h for the months of June through September 2006.

Heterozostera nigricaulis Sites 4 and 6	Average Light from 1200–1300 h (μmol/m²/s)			
Month	June	July	August	Sept
Light Under Shades (I_{shade})	7.4	4.6	15	5.7
Light Intensity at the Seabed (I_{z1})	168	162	264	288
Light Mid Water ((I_{z2})	185	203	330	342
Light attenuation coefficient (AC)	0.10	0.21	0.22	0.27
Light Sub-Surface (I_0)	248	379	629	854
% of Sub-Surface Irradiance on Seabed	68	43	42	34
% of Sub-Surface Irradiance under Shade	3.0	1.2	2.3	0.7
% of Light under shade compared to Seabed	4.4	2.8	5.5	2.0

quadrats. This may be attributed to natural variation, as demonstrated in the control sites, or possibly resulting from differences in light climate under the shades, due to the degree of fouling between cleaning events, or edge effects from some quadrats being closer to the shade edges than others.

A study into the health of the seagrass *Posidonia australis* in Jervis Bay, New South Wales, reported a rapid decline in shoot density when plants were shaded below their minimum light requirements for three months (Fitzpatrick and Kirkman 1995). Shoot densities decreased or remained low following removal of the shades and shoot numbers remained low 11 months after shade removal.

The recovery of seagrass will depend on the individual plant's carbohydrate reserves. It depends on these reserves to maintain normal functioning (Fitzpatrick and Kirkman 1995). If these reserves have been depleted to levels which prevent normal physiological function, the plants can die. Further data will need to be collected to determine whether seagrass in the recovery treatment will recover back to densities observed prior to shading.

Considering the findings of the shading study, however, and the historic data available on compensation depth (Bulthuis 1983), a minimum light requirement for *H. nigricaulis* of between 5%–13% appears to be suitable for sustaining *H. nigricaulis* beds in southern Port Phillip Bay. These minimum light requirements for *H. nigricaulis* were considerably higher than the incident light levels reported under the shades during the present study, which ranged from 1–3% of subsurface irradiance, much lower than planned, because of fouling of shade cloth. A minimum light requirement was not established for *H. nigricaulis* as part of the present study.

The AC values for July and August were comparable to the background AC for the southern Bay of 0.2 m^{-1} (Longmore *et al.* 2004); however, the light attenuation coefficient recorded for the month of June was low. This light attenuation coefficient of 0.1 m^{-1} is reflective of levels reported in Spencer Gulf, South Australia, of 0.08 m^{-1} where water clarity is high and *H. nigricaulis* has been reported in 39 m depth (Shepherd and Robertson 1989).

Observed changes, such as production of adventitious roots, flowering and leaf width differences, may be used in the future as part of an environmental monitoring program to assist with an assessment of seagrass health. We consider that the methods used here are suitable for determining the effects of a dredging plume and the time that the plume can exist before irreparable damage to seagrass occurs. As Erftemeijer and Lewis (2006) point out, site-specific experiments must be carried out and species of seagrass considered when making predictions about dredging in environmental effects statements.

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Imperial hairstreak. Photo by Michael F Braby.